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Optimization of Generation Cost for Economic Operation of Sapele Thermal Power Plant using Particle Swarm Optimization (PSO) Method

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ABSTRACT: *In the current business world, the key goal of any power provider will be to deliver electricity to consumers as economically as possible, with a greater degree of efficiency and consistency. This research analyzed the optimization of the generation cost of the Sapele Thermal Power Plant using the Particle Swarm Optimization (PSO) approach together with General Algebraic Modeling System (GAMS), by evaluating the generation cost for the thermal power plant's economic operations and activities. The research was simulated for 6 generators' test units to get automaton task learning for generation cost. From the analysis, the operation cost at which the plant is operation now is determined with respect to Economic Load Dispatch (ELD). The optimal generation schedule in 24 hours considering fuel cost, rate of pollutant emission, and thermal generation penalty cost is N11,477.78 per Megawatt-hour (NWh), while the total penalty cost of N16,473.65 /MWh. The optimal scheduling of generators with total losses of 1250.50 MW considering the highest load demand of 1050MW have total estimated cost of N66,842.83/NWh. The proposed optimization method gives cost reduction of 2% for economic operation. In the plant, some of generators are overworked and others are underworked at generating power. It is recommended that generator units with the lowest thermal generation should be compensated. The load demand can be distributed efficiently and the ELD functions effectively. All generation units need urgent maintenance and upgrade to avoid total failure, which will amount to economic operation of the plants.*

KEYWORDS: *Thermal plant, Power generation, Economic Operation, PSO, ELD*

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I. INTRODUCTION

Energy utilization provides a relative sustainable development of the national economy. Major activities strongly rely on global energy market, which means that the efficient supply of electricity at an affordable price is necessary. Modern electrical system is supplied by a number of power plants; hence economical operations of the power plants depends on minimizing the operating cost of power generation to as low as possible. The total operating cost of generators includes fuel, labour, upgrade and maintenance costs, but fuel cost is the main factor to consider when saving cost in generation, especially in thermal power plants. Other factors that affect the economic operation cost of generation includes weather condition, normal and energy conditions, equipment ratings, reserve requirements, voltage limitation, transmission losses, load scheduling, power demand and many more [1] – [5].

In Nigeria, the method of electric power generation for the last 40 years range from gas, oil, hydro-electric power station to coal fired with hydro-electric power system, but recently efforts toward renewable energy is underway [4] [8] [23]. The main fuel resources for the existing power generation plants (coal, oil, water and gas) are easily obtainable within the Nigeria. The Power Holding Company of Nigeria (PHCN), which has up of 6 Generation Companies (GENCOs), are the main consumer of fuel resources and 72% of the resources are used in power production at Afam, Ughelli, Sapele and Egbin [5] – [9]. However, over the past decade, the power demands in Nigeria has increase exponentially, while the power supply that is epileptic in nature, continue to decrease. This epileptic delivery of electric power has significant effect on the socioeconomic lives of individuals in the country [5] [9] [10] [23]. Thus there is need for operation upgrade in the electric power system. However, the cost of maintenance, fuel, labour and expansion of power generations, transmissions and distributions systems including operating and upgrading of power plants in Nigeria range into millions of Dollars [6] [10] [11]. In view of the large asset required for the desperate improvement in the electric power network, the various States in the country have task to provide a convincing amount of the total operation cost and solutions on how to economically operate on what is available, so as to contribute to expansion, continuance and maintenance of the power system [2] [12].

Artificial Intelligent (AI) methods and tools are utilized for variety of management and optimization problems [3] [13] [14]. In this research, Particle Swarm Optimization (PSO) is used to optimize the generation cost of the Sapele Thermal Power Plant, Nigeria, for economic activity and operations. The idea is to determine the overall energy costs and to find the optimal solution for economic dispatch problems, so as to reduce or manage the operating cost, especially fuel cost, of the plant despise the economic constraint in the country. PSO is a versatile swarm-based AI optimization technique. PSO can be used for power generation cost, which includes operation, upgrade and supervision of co-generation power system. The strategy of using PSO in this research is to generate the operating cost in different generation divisions at different load demands, and to get full fuel costs at the analysis of fewer costs [15] [16]. In this research, simulations were carried out for PSO using General Algebraic Modeling System (GAMS) for 6 generators' test systems at Sapele plant. The solution offered can be implemented for other thermal power plants in Nigeria.

II. LITERATURE REVIEW

2.1 Description of Sapele Thermal Power Plant

Sapele Thermal Power Plant is located in Sapele Local Government Area of Delta State, Nigeria. Fig 1 illustrates the components and working of a typical thermal power station. Sapele Power plant or station was commissioned in 1978 with installed capacity 1020MW; able to satisfy the energy needs of nearly 750,000 households at maximum capacity. This thermal station has 6 steam turbines of 120MW each and 4 gas turbines of 75MW each (totalling an installed capacity of 1020MW) and it is one of the largest in Nigeria. At the time of its commission, the plant can only provide less than 17% of the installed capacity (i.e. partially operational at 135 MW), but today, it can produce only 120MW. The reasons for partial operation of the Sapele Power Plant is unclear. Between 1997 – 2006, the percentage deficit of energy generated at the plant increased from 27.4 to 49.1 %, the load factor was between 39.9 and 64% versus the international best practice of 80%, average plant availability was less than 21% versus the Industry best practice of over 95%, and capacity factor is range as low as 5.49% in 2006 to the highest value of 17.19% in 1997. All these values indicate the plant has excessive low capacity factor, and since no improvement has been made, the power plant will gradually lead to complete failure [7] [9] [10] [17].

The deplorable and deteriorating state of the Sapele Power Plant is due to aging of the plant, improper operation and inadequate maintenance. The failure of PHCN to do advanced turn-around maintenance on the plant has also contributed to the plant's gloomy infrastructure and failure to give full capacity [9] [10] [17]. The cost of maintenance and for operation has also been claimed to contribute to the bad state of Sapele power plant and other power plants in Nigeria [5] [10]. As Energy Commission of Nigeria (ECN) estimated that the present generation facility of about 3000MW from all power plants in Nigeria have provided a massive US$150.5 billion (19 trillion Naira) as operation cost, then, to produce the extra 100,000MW needed to provide the essentials for full industrialization in the country by 2030, the monetary implication is extraordinary as it was multiplied by the growth rate of 13% [6] [10]. Performance analysis for some power plants in Nigeria was conducted in [5] and found them in similar deplorable state and suggested that thorough upgrade and frequent maintenance are urgently needed for the plants to operate at full capacity and general upkeep should be part of the operational process of the plants.

Even though the power plants in country are partially operational, there is need to economically generate power from the plants at an affordable price for both the suppliers and consumers. Factors influencing the minimum cost of power generation are:

i. Operating effectiveness of main movers along with some generators.
ii. Fuel cost
iii. Transmissions loss

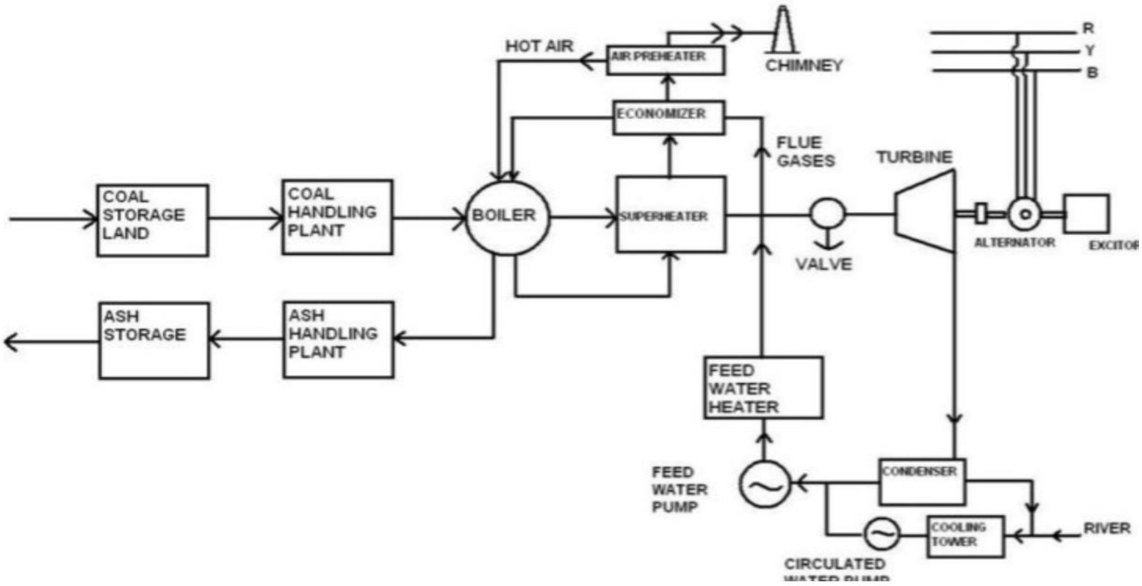


Fig. 1: Components of thermal power station

2.2 Economic Load Dispatch

Economic Load Dispatch (ELD) or Optimal Dispatch is a way of assigning production intensity to the generation division, in order to allow total power supply as well as cut cost effectively [18] [19]. ELD focus on the power generation intensity for all plants; therefore, the full costs of production and conduction are minimized for a standard schedule of load. It mainly sharpened allotment of production of each station for diverse systems load intensity [11] [15] [16]. In [3], various Heuristic algorithms were proposed for determining and optimizing the economic and environmental factors affecting Hydro-Thermal-Wind Generation Scheduling. Optimal operation of power plants with thermal storage for District Heating (DH) via non-linear programming has been investigated by [20]. A regulation designed for the reviving steam electrical plants was proposed in [21] using PSO technique to computed the ELD. The research in [22] discussed the technique use to solve ELD with a novel method based on PSO Algorithm and GAMS Software's, scheduling systems on 6 production cost system that involves different powerhouse costs, load demand and cost creation facility over a stipulated time.

The aim of ELD is to reduce fuel costs, which in turn reduces the overall cost of the whole power generation unit devoted to the load demand and requirement in the power plant, while ensuring reliability and efficiency. Minimum fuel cost is accomplished through the economic load forecast of different generation cost and plants in the energy sector. This emphasizes economic load scheduling affects the operation cost. Optimal operation and scheduling of electrical control generation system also concern the way the generator is loaded, which is very vital within the power facility industry [3] [20] [23]. The several methods of loading generators are:

i. Incremental loading
ii. Base load to facility
iii. Base load to most effective load
iv. Loading proportional to facility
v. Loading proportional to most effective load

The optimization of generation cost issue is strategies of allotting needed load to diverse generation costs during operation at minimum fuel cost, while considering the equality and inequality restriction conditions. Optimization methods apply to the planning as well as supervision of co-generation power system. AI techniques are increasingly becoming common and necessary to carry out power plant procedure involving erratic power and scheduling costs [24].

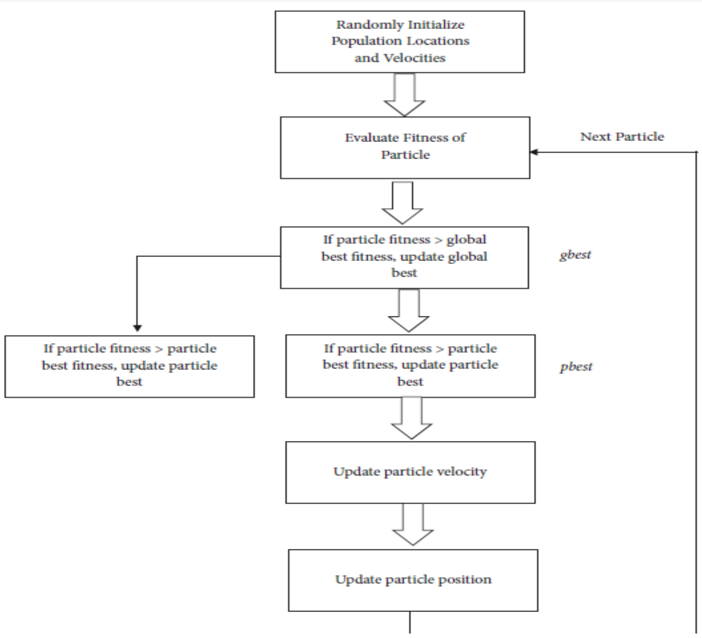
2.3 Particle Swarm Optimization (PSO)

Swarm intelligence (SI) is a branch of AI based on the collective behaviour of highly complex, self-organized, and decentralized natural and artificial systems with social structure. Most SI system mimics behaviours in nature, especially biological organisms, such as ant colonies, bee colonies, schools of fish, bacteria, flock of birds, herds of animals etc. These behaviours are translated into computationally intelligent systems. Examples of SI method are ant colony optimization (ACO), whale optimization algorithm (WOA), bacterial foraging optimization (BFO), artificial bee colony (ABC), bat algorithm (BA), glow-worm swarm optimization (GSO), PSO, and many more [13] [25] [26]. A typical SI consists of the following:

i. No central system of control that determines the way individual agents/organisms can behave.
ii. The individual actions of agents are local, but also random to some extent.
iii. Interactions between agents contribute to the creation of "intelligent" global activity that is unknown to the individual agents.

PSO technique is based on behaviour of bird flocking and socialization. The technique was introduced in 1995 by Kennedy and Eberhart and has since then have many variants [30]. It has many applications in engineering, psychology, medical, applied sciences and many more. The process is such that PSO scans through a particle swarm that changes from iteration to iteration. The new position of each particle/agent in a swarm is determined and updated by velocity term. To reach optimum solution, each particle travels along the path toward its previously best/personal best (*pbest*) position and the global best (*gbest*) position in the swarm, thus, the particles keep track of each position they have taken and reached at the moment (see Equ. 19 and 20). All particles move in group and work together towards the global best solution/near optimal resolution [13] [25] [30]. Fig 2 shows the basic flowchart of PSO and a schematic illustration of the motion of a particle in PSO. From [22] [27], some of the advantages of PSO over other related optimization methods like Genetic Algorithm (GA) are:

i. PSO is easier to use and it has smaller number of parameters to regulate.
ii. PSO has easier recollection capability. Each particle retains prior information with respect to its position and the global position, which is important to getting the optimal solution.
iii. PSO is resourceful in preserving the particle range of the group, and every particle employs the previous knowledge associated with the particle position in the global space so as to enhance for better location.



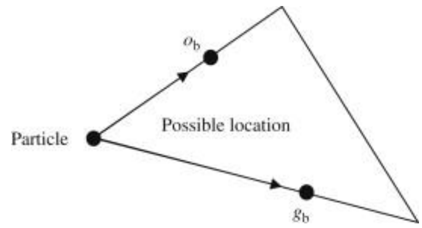


Fig 2: (a) Flowchart of PSO (b) Schematic representation of the motion of a particle in PSO [13]

2.4 General Algebraic Modelling System (GAMS)

The General Algebraic Modelling System (GAMS) is high-level modelling system for mathematical optimization involving linear, non-linear and varying integer optimization problems. GAMS is used for complex, large-scale, intricate modelling. GAMS module allows users to design complex yet maintainable models that can adapt to different and new situations. It has an easy set-up and is portable such that it can be installed and used on different computing platforms. GAMS are particularly useful for conducting large, complex, one of-a-kind problem, which might require several revisions to ascertain a precise model. The users can alter the formulation rapidly and simply, and ought to constant alter from one solver to a distinctive [28] [29].

III. MATERIALS AND METHOD

3.1 Materials

Because of the nature of this research, physical data collection was conducted at Sapele Power Plant in Nigeria (see Table 1 and Table 2), in order to identify the areas where economic improvement in power generation can be made. A line diagram based on IEEE-30 bus systems that illustrate the 6 generators' test systems at Sapele plant is shown in Fig 3.

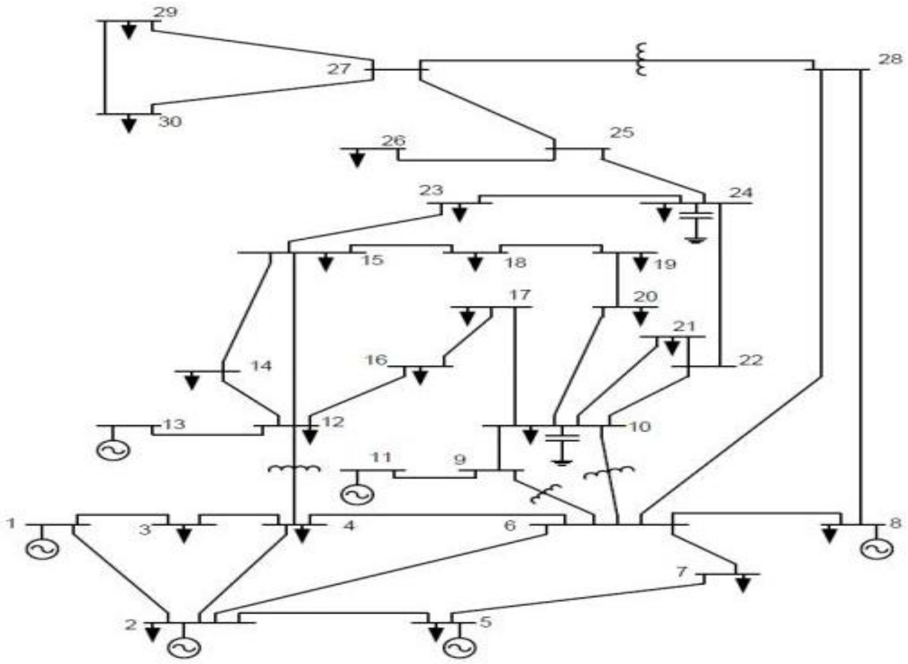


Fig 3: 30 Bus IEEE experiment system with six Generators units

3.2 Method

PSO was used in this research for the ELD or optimal dispatch to reduce operation cost especially fuel cost for Sapele Power plant. The method is to generate the operating cost in different 6 generation system at diverse loads and to get full fuel costs at the expanse of fewer costs. The basic PSO was modified with GAMS for better analysis.

The constraints used for this research are expressed in Equ (1) to (5). The operation cost of any generator unit, active power balance, loss and total demand are given by Equ (6) to (15). The quadratic objective function or cost function is given by Equ (16). PSO equations are given by Equ (17) to (23). Table 1 and Table 2 show the power plant input and power plant output for the 6 costs of the 6 generator system respectively, retrieved from records at Sapele plant. Table 3 shows the generator cost coefficient. Table 4 shows the key parameters used for the simulations.

$$P_{Gmin} < P_{Gi} < P_{Gmax} \quad (1)$$

$$S_{min} < S < S_{max} \quad (2)$$

$$P_i - P_i^{t-1} < UR_i$$

$$P_i^{t-1} - P_i \leq DR_i \quad (3)$$

$$P_{i\,min}^t = max(P_{i\,min}, P_i^{t-1} - DR_i)$$

$$P_{i\,max}^t = min(P_{i\,max}, P_i^{t-1} - UR_i) \quad (4)$$

$$P_{FK} \leq P_{FK-max} \quad (5)$$

$$FT = F_1(P_{G1}) + F_2(P_{G2}) + \cdots + F_N(P_{GN}) = \sum_{I=1}^{N} F_i(P_{Gi}) \quad (6)$$

$$\sum_{i=1}^{n} P_{Gi} = P_d + P_{loss} \quad (7)$$

$$P_G = \sum_{i=0}^{n}\sum_{i=1}^{N} P_{Gi}B_{ij}P_{Gij} + \cdots.. + \sum_{i=1}^{N} B_{01}P_1 + B_{00} \quad (8)$$

$$F = (f_1 + f_2 + \cdots + f_N) + \lambda(P_{loss} + P_d - \sum_{I=1}^{N} P_{Gi}) \quad (9)$$

$$\lambda = \frac{\partial F_1}{\partial P_{G1}} = \frac{\partial F_2}{\partial P_{G2}} = \cdots = \frac{\partial F_N}{\partial P_{G\,i}} \qquad i = 1, 2, \ldots, N \quad (10)$$

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad (11)$$

$$\lambda = \frac{dF_i}{dP_{Gi}} = b_i + a_i P_{Gi} \quad (12)$$

$$\sum_{i=1}^{n_{gen}} P_i = P_{Demand} \quad (13)$$
$$\sum_{i=1}^{n_{gen}} \frac{\lambda-\tau_i}{2\gamma_i} = P_{Demand} \quad (14)$$
$$\lambda = \frac{P_{Demand} + \sum_{i=1}^{n_{gen}} \frac{\tau_i}{2\gamma_i}}{\sum_{i=1}^{n_{gen}} \frac{1}{2\gamma_i}} \quad (15)$$
$$C_{total} = \sum_{i=1}^{n_{gen}} C_i = \sum_{i=1}^{n_{gen}} \alpha_i + \tau_i p_i + \gamma_i p_i^2 \quad (16)$$
$$X_{ij}(t) = [X_{i\,1}(t), X_{i2}(t) \cdots X_{in}(t)] \quad (17)$$
$$pop\,(t) = [X_1(t), X_2(t) \cdots X_n(t)] \quad (18)$$
$$X_{i\,j}(t+1) = X_{i\,j}(t) + V_{i\,j}(t+1) \quad (19)$$
$$V_{i\,j}^{t+1} = \beta\, V_{i\,j}^{t} + q_1 r_1^t \left(pbest^t{}_{i\,j} - X^t_{i\,j}\right) + q_2 r_2^t \left(gbest^t{}_j - x^t_{i\,j}\right) \quad (20)$$
$$i = 1, 2, 3, \ldots, X \text{ and } j = 1, 2, 3, \ldots, n$$
$$\beta = \beta_{max} - \left|\frac{\beta_{max}-\beta_{min}}{iter_{max}}\right| * Iter \quad (21)$$
$$V_i^{max} = +0.15\, P_i^{max} \quad (22)$$
$$V_i^{min} = -0.15\, P_i^{min} \quad (23)$$

Where:

P_{Gi} =Power of generator *i*, expressed in megawatts (MW); *N* = Number of generators; *FT* = Overall creation cost; P_d = total system demand; P_{loss} = total system loss; *B* = loss coefficients; P_{Gmin}, P_{Gmax} = the minimum and maximum output of generator respectively; S_{min}, S_{max} = the minimum and maximum values of reservoir storage *S*; DR_i and UR_i = upward and downward ramp rate limit of generator at a time *t*; F_i = cost function of *i-th* production cost f_i, expressed in dollars per megawatt hour (MWh) but f_i is expressed in dollars per hour); a_i, b_i, c_i = cost of coefficients of generator *i* ; P_{FK} = real power of line; K and F = number of transmission lines; $P_{FK\text{-}max}$ = maximum loading facility of the P^{th} line; *X* = position/location parameter of particle; X_{ij} *(t)* = location of the *i-th* particle with respect to the *j-th* dimension; *pop (t)* = population of PSO, which is a set of *n* particles at time *t*; *gbest* = global best position in the swarm (total particles *n*); *pbest* = previously best position *X* of each particle *i* ; *V* = Velocity vector; Q_1, Q_2 = positive acceleration constants; r_1, r_2 = random distributed variables within range [0,1]; β = the inertia weight factor to balance local and global explorations; β_{max}, β_{min} = maximum and minimum value for weight factor; $iter_{max}$ = maximum iteration number; *Iter* = current iteration number; λ is referred to as Lagrange multiplier; *C* = generation cost

Table 1: Plant Input of the 6 Costs for the 6 Generator Units

$\frac{dC_1}{dP_1}$ N/MWh	$\frac{dC_2}{dP_2}$ N/MWh	$\frac{dC_3}{dP_3}$ N/MWh	$\frac{dC_4}{dP_4}$ N/MWh	$\frac{dC_5}{dP_5}$ N/MWh	$\frac{dC_6}{dP_6}$ N/MWh	Plant λ MW
2894	3713	3438	3450	3453	3827	20775
3505	4935	4660	4675	4678	5049	27502
4600	6157	5882	5897	5900	6271	34707
5892	7379	7104	7119	7122	7493	36809
7676	8601	8326	8341	8344	8715	50003
8674	11133	10308	10338	10353	11477	62283

Source: Sapele Production Thermal Plant; N – Naira; MWh – Maga-watts per hour

Table 2: Plant Output of the 6 Costs for the 6 Generator Units

P_1 MW	P_2 MW	P_3 MW	P_4 MW	P_5 MW	P_6 MW	Plant output MW
15	15	15	15	20	20	100
20	20	20	20	35	35	135
30	30	30	30	45	45	180
35	35	35	35	55	55	235
45	45	45	45	65	65	300
50	50	50	50	70	80	350

Source: Sapele Production Thermal Plant

Table 3: Generator Cost Coefficient

Unit	$a_i(MW/N)$	$b_i(MW/N)$	$c_i(N)$	$P_{i\,min}(MW)$	$P_{i\,max}(MW)$
1	0.15240	38.53973	756.79886	10	125
2	0.10587	46.39655	451.32513	10	150
3	0.02803	40.39655	1049.9977	35	225
4	0.03546	38.32782	1243.5311	35	210
5	0.02111	36.32782	1658.5596	130	325
6	0.01799	38.27041	1356.6592	125	315

Table 4: Key parameters used in the simulations

Parameters	Values
PSO	
Swarm size (population)	15
Learning factors, c_1, c_2	2.15
Minimum iteration	500
Velocity V	$V_{min}(t) = 0.5$; $V_{max}(t) = 0.8$
GAMS parameters	
Size of Population	10
Max. Number of Iteration	500
Inertia Weight (β)	$\beta_{min} = 0.9$; $\beta_{max} = 0.4$
Acceleration constant q	$Q_1 = Q_2 = 2.0$
Convergence	1e-6
Binary Coded GA	
Size of Population b	60
likelihood of crossover	0.7
likelihood of mutation	0.1
likelihood of exclusiveness	0.15
Maximum iterations	500

IV. RESULTS AND DISCUSSION

This section presents the optimization simulation results of power generation cost for economic operation of Sapele Thermal Power Plant using Particle Swarm Optimization (PSO) method.

Table 5 shows the optimal generation schedule of the plant attained by the PSO technique, which indicate the time period, Load demand (MW) and Thermal generation of different Plant Costs. Table 6 shows the fuel cost, rate of pollutant emission, with thermal production penalty cost of the optimal generation schedule indicating the interval of time, fuel cost, production and thermal generation penalty cost in Naira per Mega-watt hour (N/MWh). Table 7 shows the optimal scheduling of generators of a Six-Cost System where load demand, loss all measure in MW. Table 8 to Table 10 give comparison of optimal cost for the 6 generator units using the AI methods of old PSO, GA and new PSO at demand of 600MW, 700MW and 800MW respectively. Load demand varies with the time interval. Fig 4 shows the system power demand indicating the load demand with respect to time intervals.

Fig 5 shows the optimal generation schedule of 6 generations' test thermal unit/plant with respect to the load demand over time. The results indicate that the highest load demand is 1150 MW at the time interval of 12 hours. The second highest load demand has 1120 MW with the time interval of 18 hours. The power demand from each generator varies with generator 5 and 6 has the highest demand while generation 1 and 2 have the lowest demand. Therefore, the generator units with the lowest thermal generation should be compensated so the load demand can be distributed and function effectively.

Fig 6 shows optimal dispatch and total cost with respect to plant costs. The result indicates the highest load demand of Plant cost 2 at 424MW with a minimum incremental fuel cost of N3,713/Mh and maximum incremental fuel cost of N11,133/MWh. While, the lowest load demand of Plant cost 5 at 97MW with a minimum incremental fuel cost of N3,453/Mh and maximum incremental fuel cost of N10,353/MWh. This indicates that the higher the load demand, the higher the incremental fuel cost both at minimum and maximum rate.

Fig 7 shows the fuel cost, rate of pollutant emission, as well as thermal production penalty cost of the best generation schedule. At the time interval of 24 hours, the highest fuel cost is N11477.78 for thermal generation penalty cost (N/MWh), which has an underestimation cost of N7181.45 and an overestimation cost of N9292.20, thus the total penalty cost of N16473.65 per MWh was estimated. While at the time interval of 1 hour, the fuel cost is N2894.78 for thermal generation penalty cost (N/MWh), which has an underestimation cost of N8254.2836, overestimation cost of N5224.11 thus the total penalty cost of N 13478.40 per MWh was estimated. Therefore, the total Fuel Cost (N/Litre) was estimated as N154,353.51 while the Total Penalty Cost (N/MWh) was estimated as N437,546.88 at the interval of 24 hours.

Fig 8 shows the optimal scheduling of generators indicating the Plant costs, losses with respect to load demand. from the results the highest load demand is 1050MW with losses of 1250.50MW at total estimated cost of N66,842.83, while the lowest load demand is 580MW with losses of 13.5MW at total estimated cost of N45500.5. Thermal plant 5 has the highest consumption MW rate and should be compensated using the other plants. Thus saving cost for maintenance as demand will shared and the risk of damage due to overworking will reduce.

Table 5: Optimal generation schedule of the thermal system obtained using the PSO method

Time Period (hour)	Load Demand (MW)	Thermal Generation					
		P_1(MW)	P_2(MW)	P_3(MW)	P_4(MW)	P_5(MW)	P_6(MW)
1	740	98.167	99.237	101.438	103.217	105.119	107.210
2	770	99.347	101.471	103.271	104.671	106.216	108.578
3	700	100.567	103.869	105.432	106.793	108.478	109.671
4	655	102.622	104.473	106.574	108.268	109.921	110.457
5	670	103.738	105.964	107.673	109.417	110.617	111.898
6	800	106.976	107.814	109.671	111.752	112.210	113.483
7	950	108.817	109.993	111.781	113.678	114.969	115.798
8	1010	109.163	110.212	112.146	114.168	115.316	116.212
9	1080	109.716	110.896	112.611	114.710	115.916	116.612
10	1070	109.669	110.876	112.567	114.617	115.871	116.467
11	1110	109.992	110.912	112.791	114.921	115.999	116.816
12	1150	112.618	112.114	113.314	115.967	116.761	117.967
13	1110	109.992	110.912	112.791	114.921	115.999	116.816
14	1035	109.212	110.367	112.216	114.216	115.417	116.368
15	1010	109.163	110.212	112.146	114.168	115.316	116.212
16	1060	109.462	110.767	112.478	114.464	115.678	116.476
17	1050	109.274	110.463	112.276	114.216	115.416	116.376
18	1120	110.673	111.483	112.987	115.261	116.214	117.147
19	1070	109.669	110.876	112.567	114.617	115.871	116.467
20	1050	109.274	110.463	112.276	114.216	115.416	116.376
21	910	107.683	108.734	110.712	112.779	113.672	114.674
22	860	107.257	108.363	110.417	112.467	113.369	114.327
23	850	107.136	108.176	110.245	112.173	113.173	114.114
24	800	106.976	107.814	109.671	111.752	112.210	113.483

Table 6: Optimal Generation Schedule with respect to Fuel Cost, Pollutant Emission Rate, and Thermal Generation Penalty Cost

Time Period (hour)	Fuel cost (N/L)	Emission (lb/h)	Thermal Generation penalty cost (N/MWh)		
			Underestimation $C_{u,i}$	Overestimation $C_{o,i}$	Total Penalty Cost (N/MWh)
1	2894.78	0.3632	8254.2836	5224.1046	13478.3882
2	3213.20	0.5499	4891.2337	12,665.7622	17556.9959
3	3438.10	0.3562	4936.0749	13,432.5058	18368.5807
4	3450.25	0.4537	5415.8092	12,288.5500	17704.3592
5	3452.50	0.1826	3626.7468	16,473.8177	20100.5645
6	3827.19	2.3600	9298.4556	4205.2730	13503.7286

7	4561.54	1.6167	5354.8522	9114.0957	14468.9479
8	4732.72	2.1204	4244.5247	12,803.0829	17047.6076
9	4967.67	7.3792	6158.0102	9116.1540	15274.1642
10	5167.93	5.3884	7885.8335	6599.0940	14484.9275
11	5324.69	2.2338	4527.4318	12,664.2699	17191.7017
12	5676.87	4.0226	2903.8506	20,708.3009	23612.1515
13	5812.96	3.9812	5976.5838	9533.7529	15510.3367
14	6467.38	5.3337	3499.9438	15,949.3590	19449.3028
15	6769.65	3.4157	4192.1110	13891.5353	18083.6463
16	7383.39	4.7289	8782.3926	6431.0096	15213.4022
17	7676.47	2.9938	1186.6187	35,327.4464	36514.0651
18	8267.33	8.1531	5656.5727	9517.6242	15174.1969
19	8674.11	5.0217	10,796.3827	3287.1198	14083.5025
20	10117.84	1.3250	2631.3055	25,212.1747	27843.4802
21	10308.76	0.6730	9844.2842	3198.1251	13042.4093
22	10337.80	0.4959	3549.8107	18,873.3735	22423.1842
23	10352.50	0.2389	3439.1051	17,504.4836	20943.5887
24	11477.78	0.2838	7181.4505	9292.1991	16473.6496
Total	154353.51				437546.882

Table 7: Optimal Scheduling of Generators of a Six-Unit System

Units	*Load Demand (MW)*	*P_1 (MW)*	*P_2 (MW)*	*P_3 (MW)*	*P_4 (MW)*	*P_5 (MW)*	*P_6 (MW)*	*Loss (MW)*	*Total Power (MW)*	*Cost (N/Hr)*
1	580	23.15	10.00	92.3	98.05	195.75	173.75	13.5	579.5	45500.5
2	650	23.40	10.00	95.57	101.80	200.75	180.95	14.21	598.26	47855.56
3	700	27.95	10.00	117.89	115.76	229.68	209.85	18.75	692.38	50168.72
4	850	32.50	13.93	140.65	135.95	236.74	223.76	25.50	758.03	55347.93
5	900	40.85	26.57	185.75	170.60	308.67	298.55	38.55	992.44	60674.98
6	1050	85.05	92.65	224.50	207.00	321.00	307.00	1250.50	-13.3	66842.83

Table 8: Six-unit cost comparison in different method, demand of 600MW

S/No	*PSO (New)*	*GA method*	*PSO (Old)*
P_1 (MW)	24.37	23.84	24.31
P_2 (MW)	10.00	10.00	10.00
P_3 (MW)	93.58	98.74	93.60
P_4 (MW)	98.86	96.79	98.01
P_5 (MW)	195.43	191.58	195.50
P_6 (MW)	183.62	189.80	183.76
Total Power (MW)	591.97	596.94	591.32
Loss (MW)	13.84	13.81	13.86
Cost (N/Hr)	45970.57	45978.60	45968.96

Table 9: Six-unit cost comparison in different method, demand of 700MW

S/No	*PSO (New)*	*GA method*	*PSO (Old)*
P_1 (MW)	27.97	28.85	27.94
P_2 (MW)	10.00	10.00	10.00
P_3 (MW)	115.85	114.74	115.73
P_4 (MW)	115.68	120.68	115.73
P_5 (MW)	228.67	227.76	228.52
P_6 (MW)	210.68	211.87	212.83
Total Power (MW)	671.29	695.58	692.39
Loss (MW)	18.38	18.32	18.36
Cost (N/Hr)	47855.56	47853.43	47850.78

Table 10: Six-unit Cost Comparison in Different Methods, Demand of 800MW

S/No	PSO (New)	GA method	PSO (Old)
P_1 (MW)	31.74	31.76	30.93
P_2 (MW)	13.57	11.46	10.94
P_3 (MW)	135.76	135.88	138.35
P_4 (MW)	138.34	138.11	142.74
P_5 (MW)	248.72	247.97	249.62
P_6 (MW)	264.15	264.33	265.96
Total Power (MW)	808.44	804.8	814.67
Loss (MW)	23.84	24.71	23.87
Cost (N/Hr)	50278.84	50275.60	50270.96

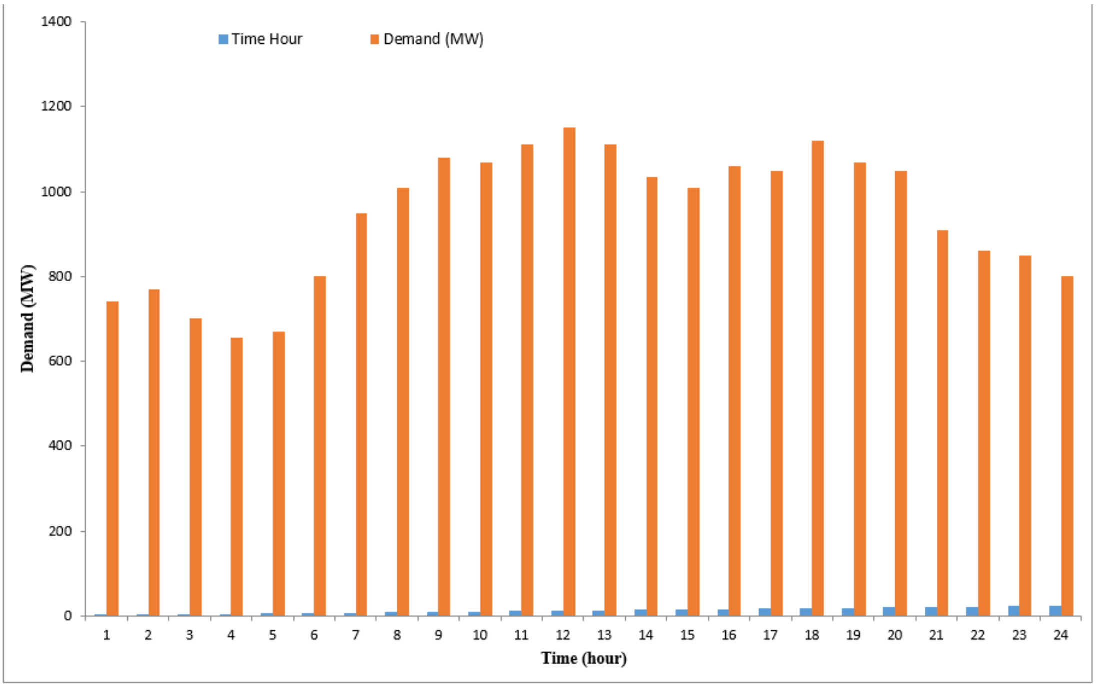


Figure 4: The System Power Demand with respect to Time Interval

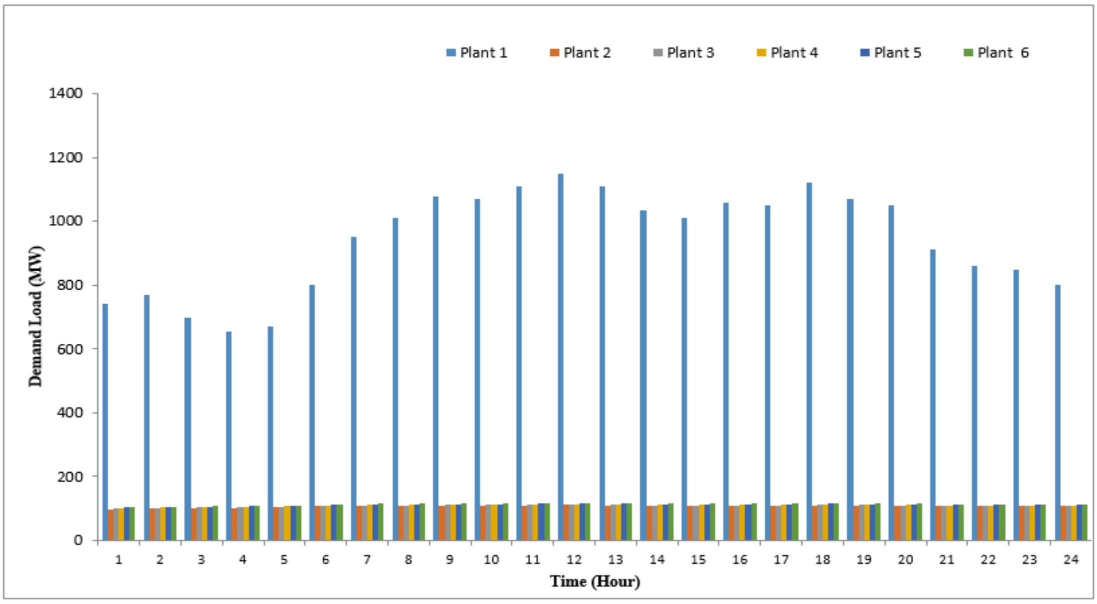


Fig 5: Optimal Generation Schedule for 6 Generations' Test Units with respect to Demand and Time

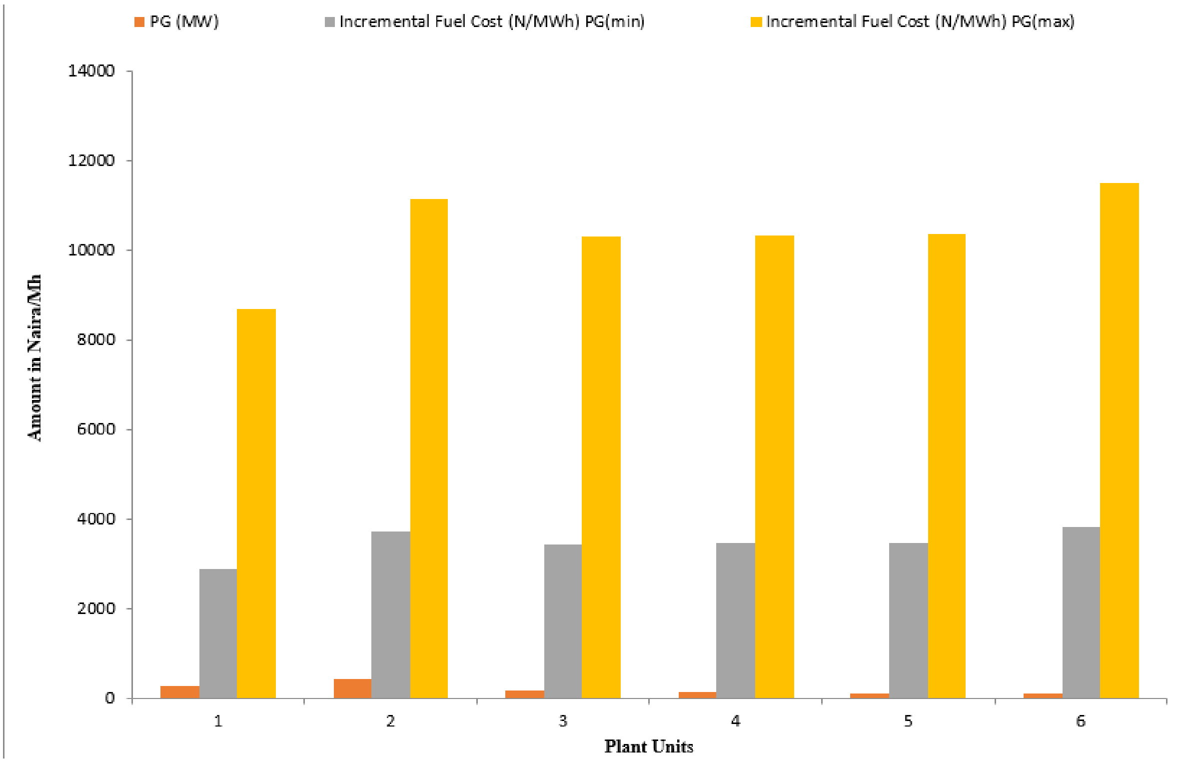


Fig 6: Optimal Dispatch and Total Cost with respect to Plant Costs

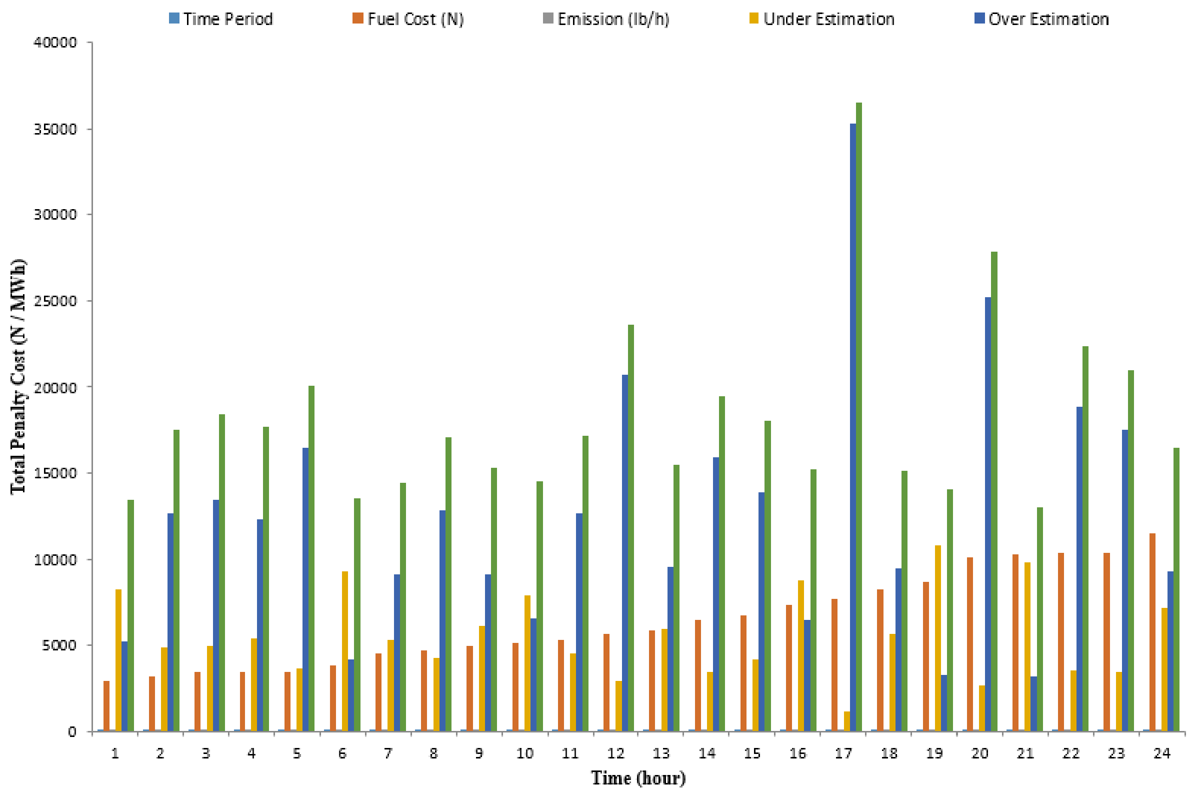


Fig 7: Optimal Generation Schedule showing Fuel Cost, Pollutant Emission Rate, Thermal Generation Penalty Cost

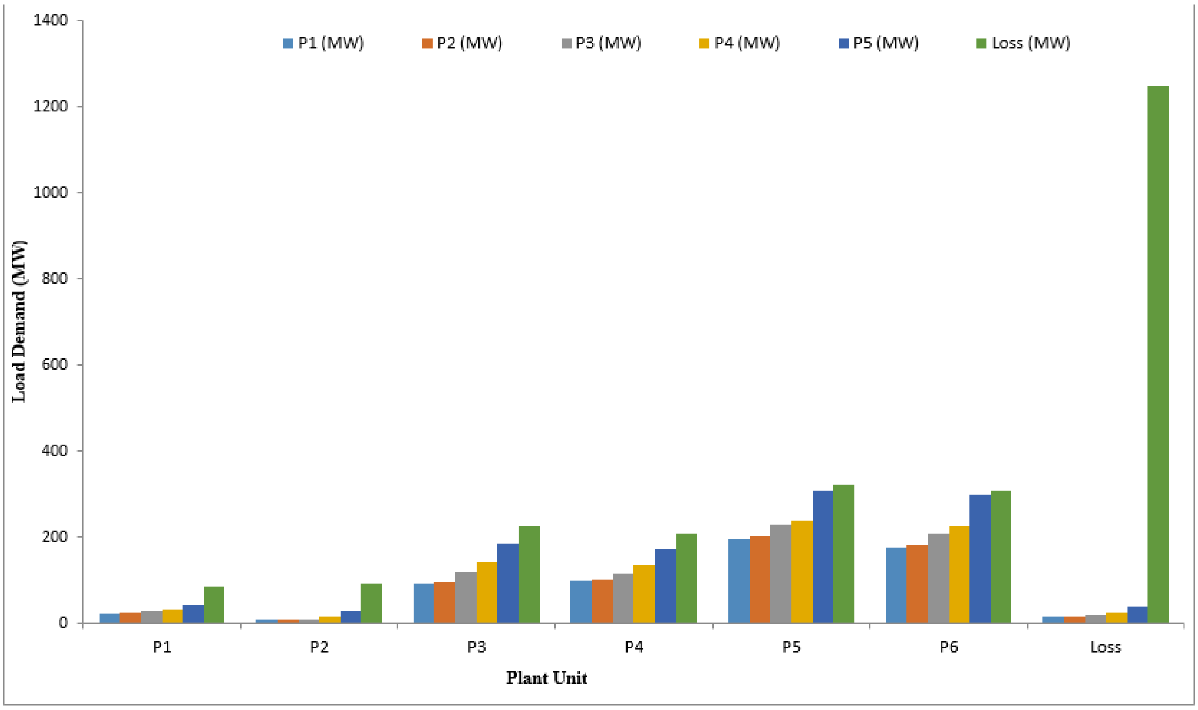


Fig 8: Optimal Generation Scheduling with respect to Load Demand, Plant Costs, Losses

V. CONCLUSION

This research examined the optimization of generation cost for economic operation of Sapele Thermal Power Plant using Particle Swarm Optimization (PSO) method. Sapele Generation plant system has a facility consisting of 1020 MW steam turbines and 450 MW gas turbines. The research analyses the generation cost to reduce operational cost, especially fuel cost, of the thermal plant. Evaluation study was done through scheduled investigation systems of production costs for different load stipulation. The PSO mixed with General Algebraic Method (GAM) test function, show to be a promising move toward for economic operation of power plants. The efficiency of the simulation is achieved for 6 generators test-units. The outcome of the analysis achieved from the new PSO technique gives improved outcome than using PSO method or GAM method independently. Some recommendations to improve the state and operational cost of power plants in Nigeria include proactive measures to ensure regular maintenance of plant facility, upgrade of the control system for plant, protection, monitoring and reliable operation, improvement in the quality and quantity of fuel resources supply (water, coal, natural gas) to the power station, improved general housekeeping of the plant, proper spare parts inventory and ensure regular training and meeting of operation and maintenance personnel.

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